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**A Hybrid Approach to the Valuation of RFID/MEMS
Technology Applied to Ordnance Inventory**

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Introduction

We report on an analysis of the costs and benefits of the Advanced Technology Ordnance Surveillance (ATOS) program undertaken by the Department of Defense (DoD), initially through its office of Advanced Concept Technology Demonstration (ACTD). The ATOS program involves fielding Radio Frequency Identification / MicroElectroMechanical System (RFID / MEMS) technology. RFID technology consists of small radio tags that transmit a radio signal identifying the tagged item, often through an electronic product code (EPC, analogous to an Universal Product Code, or UPC). RFID applications in inventory management provide one kind of Automated Identification Technology (AIT) to facilitate Total Asset Visibility (TAV). Such visibility has many benefits, such as reducing inventory shrinkage and facilitating better customer service by tracking customer orders. RFID/MEMS extend RFID by providing more information than just the identity of the tagged item. In the case of the ATOS program, the MEMS technology provides information on the temperature, gravity, and humidity experienced by the tagged items. These factors are important because they correlate with the useful life and reliability of ordnance.

DoD's ACTD office expedites promising technological solutions through the onerously long federal acquisition process, to field especially promising technology more quickly. Although ACTD projects that 'clear the hurdles' can field technology in substantially less time, the hurdles remain high – the large majority of programs proposed to this office are rejected. One of the key steps in getting ACTD approval is a compelling business case for the technology (actually this is multiple steps, as the business case must

be refined and reconfirmed at various stages). A large consulting organization that initially worked with the ATOS program office estimated a return on investment (ROI) over 1000% from implementing RFID/MEMS across the Navy.

This high ROI estimated for ATOS seems to follow a common pattern that should be viewed with skepticism given the current enthusiasm for RFID. This technology may be viewed as an operations technology like robotics, flexible manufacturing, materials requirements planning, and enterprise resource planning. Early reports of the value of such technologies often fail to be sufficiently critical. In examining management fashions, the process has been documented by Abrahamson and Fairchild (1999). The typical pattern in the literature is unrestrained exuberance, followed by hostile disillusionment, tapering into a balanced analysis just as the fashion dies.

We think the same pattern can be said to apply to the implementation of operations technologies. The objection may be raised that technologies must have a core observable functionality, while management fashion is more ephemeral because it lacks tangible substance. But as Abrahamson (1996) has pointed out, management fashion itself persists because it is not only a 'sociopsychological' phenomenon, but also a 'technoeconomic' one. The process of management fashion itself helps winnow the wheat from the chaff, and establish the boundary conditions where 'technoeconomic' benefit ends, and 'sociopsychological' enthusiasm begins. Each of the technologies listed in the previous paragraph has proven its value in some organizations, at some time. Likewise, RFID is a technology that has undoubtedly yielded some firms substantial benefits. However, we doubt that it can work for all organizations, all the time. And the current exuberance for RFID technology should, we think, give cause for special concern.

Our independent analysis was undertaken as a part of the process of getting the ATOS program approved. The ATOS office felt the 1000% ROI estimate was optimistic and wanted to conduct another independent ROI analysis. In addition, they were interested in developing a risk analysis around the ROI, to understand not just the expected rate of return but also the potential risk of receiving a lower return. Finally, they were interested in a sensitivity analysis that would show which factors most influenced the return on investment, to better understand the impact of mis-estimates of costs and benefits.

RFID Valuation

The costs and benefits of RFID have been the subject of a great deal of recent attention in the popular press (e.g., Covert, 2004). The primary consequence of RFID is, of course, better inventory accuracy. This has financial implications in several areas, including reduced shortage costs, holding costs, handling costs for missing items and the cost for not-detecting missing or unsaleable items in the incoming delivery (Fleisch and Tellkamp, In Press). In addition, labor cost may be reduced as the requirements for physical count and investigating the causes of inaccuracy are reduced. For the RFID/MEMS application we investigate, the cost of demilitarizing ordnance that has become too unreliable or volatile may be avoided by better tracking environmental conditions, which correlate with reliability and volatility, and using ordnance first (for e.g., target practice) that has the greatest chance of becoming obsolete or unreliable.

However, not all of the benefits of RFID are easily quantifiable, as is true of any advanced operational technology. The application of technology to facilitate logistics and operations is as old as the industrial revolution. However, the recognition that such

technology is difficult to value using traditional cost accounting methods is more recent and coincides with the widespread adoption of process automation and computer integrated operational technology.

In an early work, Kaplan (1986) tried to make the case that discounted cash flow analysis might still be usefully applied to value computer integrated technology, but that discount rates should be lower than those applied to conventional projects, to account for strategic, difficult to quantify factors.

The valuation of advanced technology has produced an enormous literature. A recent comprehensive bibliography listed over 200 papers dealing with the valuation of advanced *manufacturing* technology alone (Raafat 2002). Many authors since Kaplan have recommended dealing with strategic, qualitative factors more explicitly. Some have recommended estimating the value of those factors as best as possible and explicitly including them in the financial analysis (Primrose 1991). Others have recommended a hybrid approach, in which qualitative factors are considered in a complementary analysis (Kakati and Dhar 1991). Empirical work has found that many firms do not use sophisticated valuation techniques, but those firms using a hybrid justification approach tend to have better outcomes with technology implementations (Small and Chen 1997).

The qualitative factors most often cited by firms evaluating advanced manufacturing technologies include flexibility, learning, quality, reliability and safety (Saleh, Hacker et al. 2001). The first two of these have been of particular importance in advanced manufacturing technology. Flexibility is a key benefit behind Flexible Manufacturing technology and organizational learning is often cited as a key benefit to many business software technologies. Because of this, specialized techniques have been proposed to

evaluate those factors: researchers have attempted to capture the value of flexibility through combined simulation and linear programming approaches (Ramesh and Jayakumar 1997); valuing learning, and particularly learning and knowledge acquisition through information technology, has been the focus of whole new methodologies, such as Fuzzy Cognitive Mapping (Irani, Sharif et al. 2002) and Knowledge Value Added (Housel and Bell 2001). The primary qualitative benefits of RFID, however, revolve around quality and reliability; the unique benefit of the RFID/MEMS application we are evaluating, as we shall show, is safety.

Method

The cost-benefit investigation of this proposed RFID/MEMS implementation used both qualitative and quantitative methods. Qualitative methods included a factorial structure for the non-cost related benefits of the implementation; quantitative methods involved a traditional ROI analysis to assess the value of implementing RFID, supplemented with a sensitivity and risk analysis of key factors.

Assessment of Qualitative Benefits

A factorial structure for the qualitative benefits of this program was developed through a combination of case based methods and multi-criteria decision techniques. Extensive unstructured interviews were conducted with five current members of the ATOS program office and two former members. Each of these interviews was recorded and then transcribed for later coding and analysis. Follow-up interviews were conducted with two of the participants and other participants responded to email queries about their interview responses. Building on these transcripts and existing theory, we developed a

set of qualitative factors, representing benefits obtainable through the RFID/MEMS implementation.

To capture the utility of these qualitative factors, we conducted a pilot survey with five potential users (managers) of this technology at an ordnance depot on the west coast of the United States. These initial surveys collected open-ended, unstructured data as well as utility assessments – each interview was time consuming for the participants and the researchers. The survey instrument contained questions to assess the relative utility of the factors. In addition, we asked participants to assess the relative benefits of (1) ATOS, (2) the status quo (no technology) and (3) a simple bar coding scheme, on each of the factors. A swing weighting technique was used to assess relative utility (von Winterfeldt & Edwards, 1986). These swing weights were then converted to simple multiple attribute ranks and input into a multicriteria decision support tool to obtain factor and alternative rankings, as well as sensitivity analyses on the utility assessments. While swing weights are not intended to be equivalent to simple multi-attribute ranks, recent work suggests that various multiple criteria weighting techniques tend to produce convergent results (Poyhonen & Hamalainen, 2001).

In addition to the utility assessment, the survey also included several open ended questions to understand the reasoning behind the participants' responses and to insure that we had not left out important qualitative factors. Completing the survey, including training in the relevant multi-criteria technique, required a half-day from each participant.

What we report here was originally intended as a pilot experiment, prior to a more rigorous examination of qualitative factors related to the RFID/MEMS implementation.

When discussing the results, we will examine the reasons the more comprehensive analysis was not undertaken and the potential consequences of the omission.

Assessment of ROI

As with all public sector investments, there is no revenue stream to estimate as an outcome of the investment. Instead, returns for public sector ROI projects are often taken from cash flow changes based on estimates of cost reductions, cost avoidances or funding deficiency reductions.

Funding deficiency reductions essentially represent an opportunity cost to current expenditures. All government agencies, and many government programs, have expressed needs that remain unfunded by congress. Within certain (fairly stringent) limits, a program manager may be able to apply cost avoidances and cost reductions to meet unfunded requirements. To the extent it is possible to value those unfunded requirements, e.g., reductions in inventory, The ROI might be estimated by the value of the forgone alternative investment. However, this research takes a conservative approach and does not explicitly examine funding deficiency reductions or other opportunity costs.

Cost reduction and cost avoidance have an important distinction: cost reduction represents decreases in outlays already obligated; cost avoidance, however, eliminates anticipated expenditures that have not been obligated. In the case of cost avoidance, the government retains the option to avoid the cost by reducing services, which confuses ROI estimates: can cost avoidance be fully considered a benefit of current investments if DoD could choose to avoid these costs in other ways? The distinction is not clear cut, however. Funds for future year maintenance of existing weapon systems, for example,

are not obligated in many instances; reducing anticipated future year maintenance expense might be treated as cost avoidance. However, the government has no cost-free option to avoid maintaining these weapon systems, or, at a minimum, de-militarizing and disposing of these systems in some future year. Our analysis does not distinguish between cost reduction and cost avoidance, on the assumption that the government will not otherwise reduce services related to ordnance storage and maintenance.

The ROI calculation we report is based on the standard formula for the Internal Rate of Return, with changes in expected expenditures, or cash flows, taking the place of revenue – cost. That is, the return on investment will be calculated as the discount rate that makes the net present value (NPV) of cash flow changes equal to zero:

$$IRR = i \ni NPV = \sum_n \Delta E[cashflows] / i = 0 \quad (1)$$

In addition to the ROI, we will also report the NPV using the recommended discount rate of 5% for Federal Government investments in technology infrastructure.

The ROI calculations are based on implementing RFID in the US Navy and the US Marine Corps only. A portion of US Navy and US Marine Corps ordnance inventory is stored, at least temporarily, by other agencies, including the US Army. This analysis ignores the impact of this cross-organizational handling and storage, on the assumption that tag information will either be tracked by the other agencies (the US Army had one of the first RFID programs) or that the tag information can be obtained in a timely fashion when custody changes hands.

Factors significant for cost avoidance and cost reduction

From the plethora of ordnance related costs, the costs not expected to be impacted by RFID/MEMS insertion are excluded. The costs that are expected to be reduced by RFID/MEMS are:

- Inventory Labor - Includes all costs to perform execution, reporting, inspection, safety, ammunition management and accountability review. This cost is included in anticipation that applications will use RFID/MEMS data to automate some portion of these tasks.
- Causative Research - Includes all costs to reconcile inventory reports with physical counts. This factor is included in anticipation that improvements of asset visibility will reduce the need for such research.
- Transportation - Includes all costs to perform second destination transportation, including distribution, redistribution, surveillance, maintenance, and demilitarization. This is included in the expectation that some portion of this cost is due to errors in ordering or handling, and that this portion will be reduced by the introduction of RFID/MEMS technology.
- Demilitarization, Maintenance and Surveillance (DMS) - Includes the cost of personnel to perform DMS, as well as variable storage expense related to DMS. This factor is included in anticipation that some portion of this cost could be avoided, if older ordnance could be used first, and potentially less reliable ordnance could be used for training.

A set of cost reduction and cost avoidance point estimates were developed by a consulting organization for the ATOS program office, and these estimates formed the basis for this research. Additional interviews with subject matter experts and our own expertise in Military Budget Accounting, Operations Management and Economics were used to modify the point estimates (in every case the cost savings estimate became more conservative) and to make distributional assumptions around the point estimates.

Data sources and subject matter experts consulted for cost avoidance and cost reduction estimates included: a Receipt, Storage, Stowage & Issue (RSS&I) program manager, Weapons Officers at Naval Air Stations; Ship Weapons Officers; Ammunition Management and Accountability Review (AMAR) publications; 1996 Projected RSS&I requirement with Fleet Ownership; 1997 DoD Joint Operations for Explosives Report; the Defense Transportation Tracking System Program Manager; the Navy Supply Corp Transportation Director; Weapons Support Facility Public Works Coordinators and Ordnance Officers at Seal Beach, CA and Yorktown, PA; a former Navy Surveillance Program Manager; personnel at the Marine Corps Programs Department in Fallbrook, CA; and Navy Total Asset Visibility Automated Identification Technology Project – Sidewinder Touch Memory Button Maintenance Records.

Cost reduction and cost avoidance estimates are shown in Table 1. No benefits are expected in the three years following the study. Benefits begin to accrue in the fourth year as the RFID/MEMS technology is deployed. Full deployment is expected to take four years and benefits are expected to increase as deployment goes forward. Costs are expected to stabilize after the technology is fully deployed to those shown in Table 1 for year seven.

Table 1. Cost Reduction and Cost Avoidance Factors
Constant 2003 dollars (millions)

	Inventory Labor	Causative Research	Transportation	DMS	Total
Status Quo	54.4	25.5	6.8	248.0	334.7
ATOS FY01	54.4	25.5	6.8	248.0	334.7
ATOS FY02	54.4	25.5	6.8	248.0	334.7
ATOS FY03	54.4	25.5	6.8	248.0	334.7
ATOS FY04	49.4	20.4	5.4	206.5	281.7
ATOS FY05	44.4	15.3	4.1	165.0	228.8
ATOS FY06	39.3	10.2	2.7	123.5	175.7
ATOS FY07	34.3	5.1	1.4	82.0	122.8

The expected investment costs required to deploy the RFID/MEMS technology are:

- Modification of Commercial-Off-The-Shelf (COTS) RFID/MEMS - The program office cost to design, modify, test, and demonstrate an inventory / surveillance system based on COTS technology.
- Procurement - The cost to award and execute a contract for the manufacture of all components and fielding of the system, Navy-wide, including preprocessors, portable and fixed readers, radio frequency extenders, tags, installation and training costs .

The consulting organization initially assisting the ATOS group again provided point estimates for these investment costs, and we conducted additional investigation. Our

estimates of procurement costs were somewhat higher than the initial estimates. Procurement and modification cost estimates are shown in Table 2. Procurement and modification costs are based in part on actual costs incurred during a demonstration at the Indian Head Division, Naval Surface Warfare Center. Other data sources and subject matter experts consulted in developing investment cost estimates include: the Department of the Navy FY98/FY99 Biennial Budget Estimate for Operations and Maintenance; FY97 NAVSEA Instruction 8023.7 – Space Utilization and Storage of Explosives and Inert Ammunition; and price quotes from three manufacturers.

Table 2. RFID/MEMS Investment Costs
Constant 2003 Dollars (millions)

	COTS Modification	Procurement
FY01	5.3	0
FY02	4.2	0
FY03	4.6	0
FY04	0	7.3
FY05	0	7.3
FY06	0	7.3
FY07	0	7.3
FY08	0	4.5

Although some systems development is also required to exploit the RFID/MEMS data that the ATOS implementation will generate, these costs were not estimated directly, beyond the cost of designing and implementing a database and application programming interface (API) for the RFID/MEMS data. This primarily reflects a large number of software redesign efforts already underway; it is anticipated that, given a well designed data base and API, already planned systems could incorporate and use RFID/MEMS data. As mapping these system development efforts and any incremental cost they might incur

to acquire RFID/MEMS data was beyond the scope of this project, we chose to implicitly represent this factor by modeling variance in the cost reduction associated with RFID/MEMS. That is, we modeled additional software development efforts that *might* be required as a risk of *less* cost reduction and cost avoidance.

Sensitivity and Risk Analysis Elements and Scenarios

The sensitivity analysis was conducted by varying key elements of four factors: 1) procurement and COTS modification, 2) status quo cost reduction and avoidance, 3) technology obsolescence, and 4) implementation schedule and training. Each of these factors was changed in turn, *ceteris paribus*, constituting an analysis of four separate scenarios. The risk analysis was conducted by first determining appropriate distributions for key elements of the four factors listed above, then using a Monte-Carlo simulation of 1,000 trials to determine the 5th and 95th percentiles of the ROI and NPV that could be expected. A risk analysis was conducted for the base case and in each of the four scenarios used for sensitivity analysis.

For the first (procurement) scenario, the following elements were all increased by 25% from their values in the base case: COTS modification cost; usable magazines per major (and minor) weapons depot site; amount of ordnance items (and cases) to be tagged; unit costs of fixed readers, portable readers, hand-held readers and tags; number of frequency extenders required; the number of hand-held and portable readers required per site; the per site hardware and software installation costs; and all hardware replacement rates.

For the second (cost reduction and avoidance) scenario, the following elements were all decreased by 25% from their values in the base case: reduction in cost (below status

quo) of labor for reporting, causative research, and DMS; reduction in out of pocket DMS holding costs; and reduction in transportation cost.

The third scenario addresses the issue of technology obsolescence. Based on depreciation rates, and rates of technological change in related industries, we felt that the 20 year life-cycle that the consultants initially forecast might be optimistic. While we did not make a systematic effort to obtain a better life-cycle estimate, we did want to investigate the sensitivity of NPV and ROI to technology obsolescence. To do this, we varied two parameters: we reduced the number of benefit years by 25% from 20 to 15; and we increased the discount rate (to account for added risk) by 25% from 5% to 6.25%.

The fourth scenario addresses schedule risk. The pilot results from our qualitative factor utility assessment led us to believe that the implementation time line and cost estimates for this technology might be optimistic. Again, we did not make a systematic effort to obtain a better estimate, but instead modeled the sensitivity of ROI and NPV to changes in the implementation schedule. To do this, we modified the planned roll out shown in Table 2 (25% in years 4-7) to 18.75% in years 4-8 and 6% in year 9. We also increased training cost estimates by inflating both the estimated training hours required and the number of personnel who require training by 25%.

To conduct the risk analysis, we assigned distributions to each of the model's major elements. For most cost elements, subject matter experts estimated minimum and maximum values around our initial cost estimates and we assumed a triangular distribution. When we could not obtain estimates of minimum and maximum values, we assumed an exponential distribution in most cases (because an exponential distribution requires only a single parameter). A few variables had percentage estimates that were so

high (e.g., 80% reduction in causative research labor cost) that an exponential distribution yielded unrealistically large potential savings. In those cases we assumed a triangular distribution, with a narrow range of variability (10%) around the estimated mean. Distributional assumptions are shown in Table 3, except for a few variables that the ATOS program office requested we keep confidential (e.g., Tag Cost).

Table 3. Distributional Assumptions for Model Elements in Risk Analysis

Variable	Distribution	Mean	Min	Max
Unit Cost of Fixed Readers	Triangular	\$ 1,000	\$ 500	\$ 1,500
Unit Cost of Portable Readers	Triangular	\$ 1,000	\$ 800	\$ 1,200
Unit Cost of Hand-Held Readers	Triangular	\$ 2,500	\$ 2,300	\$ 2,700
Unit Cost of Frequency Extenders	Triangular	\$ 50	\$ 48	\$ 52
Cost of H-ware Installation per Site	Triangular	\$ 7,400	\$ 5,000	\$ 10,000
Avg. Cost for Software Installation per Site	Triangular	\$ 1,500	\$ 1,350	\$ 1,650
No. of Personnel to be Trained	Triangular	1070	930	1130
No. of Hours Required per Person	Triangular	8	12	24
Annual Scheduled Tag Replacement	Exponential	20.0%		
Annual Frequency Extender Failures	Exponential	3.0%		
Annual Tag Failures	Exponential	0.5%		
Annual Fixed Reader Failures	Exponential	1.0%		
Annual Portable Reader Failures	Exponential	5.0%		
Annual Handheld Reader Failures	Exponential	5.0%		
Report Labor Savings (% of SQ Report Costs)	Triangular	75%	65%	85%
Causative Research Labor Savings (% of SQ)	Triangular	80%	70%	90%
Transportation Redistribution Savings (%SQ)	Triangular	80%	70%	90%
DMS Out of Pocket Holding Cost Savings (% of SQ)	Triangular	50%	40%	60%
DMS Surveillance & Maintenance Labor Savings (%SQ)	Triangular	60%	50%	70%

Results

This section reviews the results of our analyses, beginning with the multi-attribute factorial structure that emerged from the literature and unstructured interviews, followed by the ROI and NPV risk and sensitivity analysis.

A factorial structure of the benefits of RFID/MEMS

Interviews with one of the military executives who started the program that evolved into ATOS, disclosed that the program's original intent was not asset visibility, but rather safety improvements. While investigating an explosion at a bunker at the Indian Head Naval Base, Maryland, it was discovered that degradation in ordnance containers had allowed propellant to escape and accumulate in the bunker until it spontaneously ignited. While there were no fatalities in the incident, the clean up cost over \$2 million dollars. An article on RFID/MEMS technology came to the attention of the officer in charge of the investigation (the person we interviewed), who realized that automated monitoring of the ordnance would have prevented the accident. Interview subjects from the ATOS program office uniformly felt that safety was both a prime motivator and a significant benefit from implementing this RFID/MEMS technology.

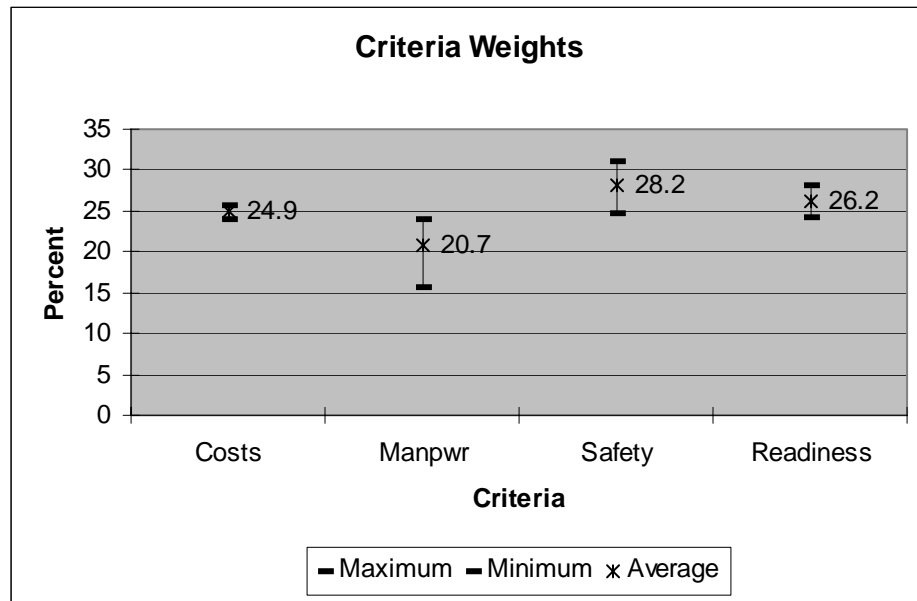
Other qualitative factors mentioned in our literature review also seem relevant here, in particular quality and reliability. Subject matter experts from the ATOS program office confirmed the importance of quality and reliability, citing the impact of maintaining reliable asset visibility and improving ordnance quality by reducing obsolescence. Making ordnance more visible on a global basis and closely tracking the environmental exposure of that ordnance would improve operational performance. This factor was labeled Readiness in our analysis. Readiness means (among other things) the

degree to which assets are ready to be used for military contingencies: the percent of assets that are in full working condition.

Finally, subject matter experts felt that the head count reduction attainable by implementing RFID/MEMS has qualitative benefits beyond those measured in dollar terms. These benefits include the operational value obtained by re-assigning personnel to tasks more significant than tracing misplaced inventory or conducting physical inventory counts. Not only are these routine tasks non-value-added, they are disliked by those doomed to perform them, lowering work satisfaction and the quality of work life. Conversely, the learning that would occur for those that deployed the RFID/MEMS technology would improve their craft skills and the job enrichment would likely increase satisfaction. Thus, a head count reduction associated with these tasks not only improves the effectiveness of ordnance management by freeing resources for more important tasks, it likely improves job satisfaction and quality of work life (and hence retention; Maertz & Campion, 2004) for those employees engaged in ordnance management.

Thus, a complete picture of RFID/MEMS utility needs to include at least 3 qualitative factors: safety, readiness, and manpower. While it was beyond the scope of this investigation to attempt to measure these qualitative factors across the DoD, we proposed to develop a tool that the ATOS program office, or individual commands, could use to assess them, especially the magnitude of the perceived benefits relative to the cost-reduction benefit.

Figure 1. Range and median of criteria weights



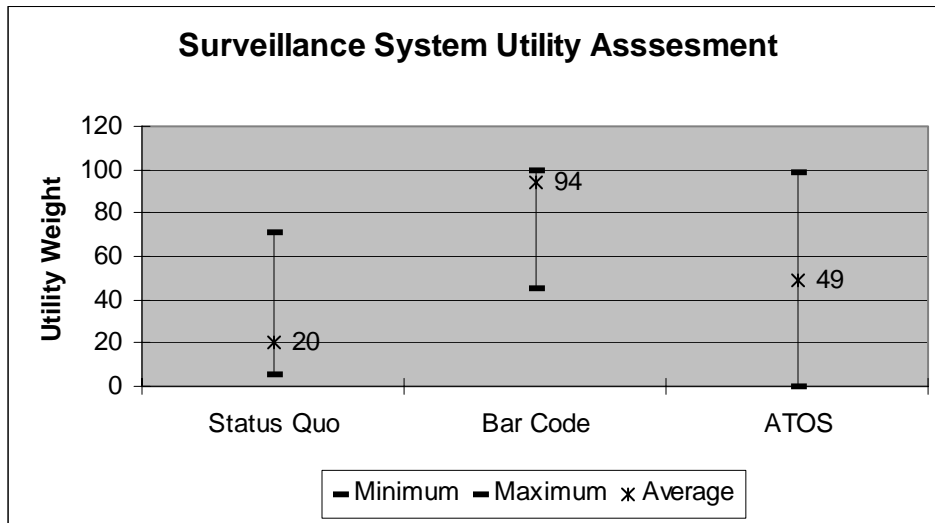
Relative importance of benefits (criteria)

The criteria weights that emerged from the second survey of potential RFID/MEMS users are shown in Figure 1. The five respondents all scored either safety (3/5) or readiness (2/5) as the most important criterion. No respondent ranked cost-reduction as the primary criterion and only one subject ranked cost-reduction as the second most important criterion. These results are discussed below.

Relative utility of RFID/MEMS versus Bar-coding or the Status Quo

Only one respondent gave RFID/MEMS a higher utility than the bar code system; two respondents ranked it below the status quo. Figure 2 shows the median estimate and associated range for the relative utility of the alternatives. Based on responses to our open-ended questions, we think these scores reflect factors beyond utility assessment.

Figure 2. Utility of Tracking System Alternatives



Several respondents brought up implementation issues during open ended discussions, although it was not a question we discussed directly. For example, one respondent commented that RFID/MEMS and Bar-coding were “level” because of the “human factor”, and that RFID/MEMS “wouldn’t work everywhere on all asset types”.

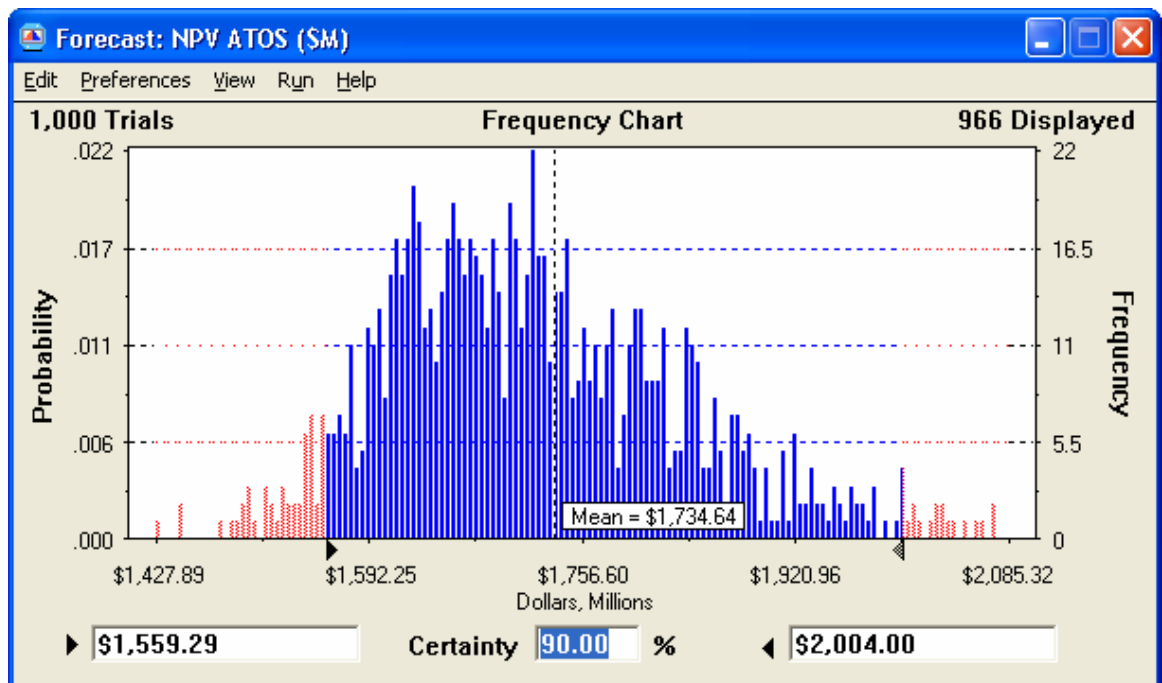
Respondents also volunteered their frustration with “similar” technological implementations. For example, one respondent suggested: “Before any additional money is spent on new technology we need to first ensure that old technology is being used. Common sense, basic warehousing, and management oversight are the keys regardless of what type of whiz-bang system we have”.

Thus, rather than merely assessing the utility of successfully implementing RFID/MEMS, participants seemed to confound two factors: skepticism regarding the implementation of RFID/MEMS and a sense that RFID/MEMS doesn’t address the highest priority ordnance management issues.

ROI estimates, Risk and Sensitivity Analyses

Results for the risk and sensitivity analysis are summarized in Table 4. Based on the costs in Tables 1 and 2, and using a 5% discount rate and a 20 year expected life, we estimate that the expected ROI for this RFID/MEMS application is 154.8%. Using Monte Carlo simulation and the distributional assumptions shown in Table 3, Risk analysis estimated the 5th and 95th percentile as 148% and 165.6%, respectively. That is, there is no more than a 5% probability of a return lower than 148% and at least a 95% probability that the return will be lower than 165.6%. A sample graph showing the distribution of ROI outcomes for the base case is shown in Figure 3. The expected NPV was \$1.737 billion dollars, with 5th and 95th percentile estimates of \$1.556 billion and \$1.995 billion, respectively.

Figure 3. Probability Interval for Base Case NPV



The first sensitivity analysis dealt with procurement costs. As detailed in our methods section, we increased key procurement elements by 25% to investigate the sensitivity of our reported returns to changes in procurement costs. The expected ROI is 137.8%, with 5th and 95th percentile estimates of 130.2% and 149.3%. The expected NPV is \$1.721 billion, with 5th and 95th percentile estimates of \$1.505 billion and \$1.962 billion. The insensitivity of NPV to changes in procurement expenditures is discussed in the next section.

The second sensitivity analysis dealt with a 25% reduction in key elements of the cost reduction and cost avoidance benefits. The expected ROI in this scenario is 138.2%, while the 5th and 95th percentile estimates are 128.4% and 153.4%, respectively. The expected NPV is \$1.361 billion, while the 5th and 95th percentile estimates are \$1.157 billion and \$1.708 billion, respectively.

The third sensitivity analysis dealt with technology obsolescence and a shorter-than-expected RFID/MEMS technology life cycle. The expected ROI in this case is virtually unchanged from the base case at 154.9%, as are the estimates of the 5th and 95th percentiles. The estimated NPV, however, was reduced to \$1.167 billion, and the 5th and 95th percentile estimates were \$1.051 billion and \$1.350 billion. We will discuss the reason for this difference in outcome measures below.

The final scenario dealt with slippage in the implementation schedule and unexpected increases in training cost and time. In this case, the expected ROI was reduced to 138.8%, while the estimates of the 5th and 95th percentile were reduced to 131.9% and 148.8%. The NPV estimate dropped to \$1.657 billion, with estimates of the 5th and 95th percentile at \$1.467 and \$1.938 billion.

Table 4. Risk Analysis of ROI and NPV
NPV in millions

Scenario	5% Prob. NPV < X	Mean NPV	95% Prob. NPV < X	5% Prob. ROI < X%	Mean ROI%	95% Prob. ROI < X%
Base Case	\$1.556	\$1.737	\$1.995	148.0%	154.8%	165.6%
1. Procurement	\$1.505	\$1.721	\$1.962	130.2%	137.8%	149.3%
2. Cost Red. & Avoidance	\$1.157	\$1.361	\$1.708	128.4%	138.2%	153.4%
3. Tech. Obs.	\$1.051	\$1.167	\$1.350	148.2%	154.9%	165.2%
4. Schedule Risk	\$1.467	\$1.657	\$1.938	131.9%	138.8%	148.8%

Discussion and Limitations

Discussion and Synthesis of Results

The factorial structure of benefits that we derived from our literature review and the unstructured interviews seems to capture the important benefits to be obtained from implementing RFID/MEMS. Our subsequent interviews with potential technology users did not uncover any additional factors and showed that each of the factors we had derived was valued by those users.

While the results of such a small sample have quite limited generalizability, for these users analyzing only the potential cost reductions would not be sufficient. The difference in criteria weights between “soft” and “hard” criteria is not large (e.g., 28.2 for safety compared to 24.9 percent for cost). However, these results indicate that a cost-benefit analysis that ignored “soft” criteria, such as safety and readiness, would omit both the primary benefit and the majority of the benefit (i.e., over 50% of the utility) anticipated by these users.

If one assumes that ATOS will create net benefits in safety and readiness, these pilot results also imply that a cost-benefit analysis which justified ATOS on “hard” criteria alone would be extremely conservative, significantly understating the total value of the program, at least for these users.

Nonetheless, the ATOS program office chose not to pursue a broader utility survey at this time, and chose not to incorporate soft-criteria and cost data together in a systematic analysis of alternatives with, for example, a Data Envelopment Analysis. In part, this probably reflects that the output from the cost analysis was so overwhelmingly positive. Even if one agrees that cost captures less than $\frac{1}{2}$ the potential utility, when the estimated ROI is over 150% and the estimated NPV is over one billion dollars, it is difficult to justify the efforts to analyze additional benefits.

In spite of the large returns estimated from implementing RFID/MEMS, the potential direct beneficiaries of the technology indicated significant skepticism and a sense of working from the wrong priorities in our interviews. Their comments may represent a serious barrier to implementing RFID/MEMS. The extent to which other stakeholders have similar perceptions is impossible to judge based on qualitative responses from five participants in this pilot study. But if there is widespread skepticism about the implementation, or a widespread belief that resources directed to RFID/MEMS are being poorly used, it may reduce the benefits realized from the system or even prevent its full successful implementation. While one expects that employee support may not be such a critical factor in a hierarchical military environment, work in socio-technical systems suggests that employees often find costly covert ways to express themselves when they feel they cannot voice their discontent openly (Graham, 1993).

We proposed that the ATOS program office conduct a survey of implementation barriers among potential RFID/MEMS users, to fully assess the resistance to the implementation and to inform educational efforts to address those barriers. However, to our knowledge such a survey is not planned before implementation. This may be because the need to educate lower-echelon managers about the priorities and values behind decisions is not recognized in the military organizations targeted for ATOS implementation. Indeed, it is possible that such an educational effort, if it were perceived as a ‘justification of orders’, might be counterproductive in a military environment. There was some evidence that ATOS stakeholders felt an analysis of barriers might do more harm than good; for example, on seeing the results of our survey indicating resistance at specific locations, one stakeholder responded by saying “we’ll make sure and implement it there first.”

To incorporate the effects of institutional resistance to RFID implementation, our sensitivity analysis did include a scenario in which implementation is delayed and training costs increase (Scenario 4 in Table 4). We do not claim that our schedule delays and training cost increases in any way represent a ‘worst case’ scenario, but the results do indicate that returns are fairly insensitive to changes in implementation schedule. One could argue that a \$100 million reduction in NPV with a 25% longer implementation and 25% increased training cost is quite significant, however, this is only (roughly) a 5% reduction in NPV. So, while the dollar impact is large (and potentially worth further investigation), the expected return seems fairly robust against moderate difficulties in implementation.

Another interesting result of our sensitivity analysis was the impact of technological obsolescence. While a 20 year life span seems optimistic for this kind of technology, reducing that life span to 15 years produced virtually no change in ROI. However, reducing the life span to 15 years and increasing the discount rate to 6.25% produced a fairly substantial reduction in expected NPV estimates, from \$1.737 billion to \$1.167 billion (a 33% reduction). The similarities in ROI and differences in NPV can be explained, in part, by noting that the increase in the discount rate does not affect ROI, since the IRR *is* a discount rate, but significantly reduces the NPV. Similarly, the reduction in lifecycle does not affect ROI because returns in the out years are virtually meaningless with IRRs ranging from 14.8% to 16.6%; lifecycle reductions have a bigger impact on NPV with a 6.75% discount rate. (We verified that both the lifecycle change and the discount rate change had an impact on NPV.) The IRR is high, of course, because the dollar value of the benefits is so much larger than the dollar value of the investments. This is a known issue with IRR as an investment measure and illustrates the importance of using more than one measure of return on investment.

The importance of having both measures can also be seen in the analysis of our first scenario, in which procurement costs increased. In this case, the impact of a 25% procurement cost increase was an 11% reduction in the ROI estimate, but only a 1% reduction in NPV. The difference can again be seen in the relative importance of early year returns in the ROI calculation with a 15.5% discount. The change in procurement cost is dwarfed by subsequent returns in the NPV calculation (with a 5% discount rate).

Finally, given the sizeable cost reductions expected from this RFID/MEMS implementation, the most important sensitivity analysis may be scenario two, which

investigated reductions in anticipated benefits. This scenario is doubly important because it is the only sensitivity assessing simultaneous cost reduction initiatives, which may reduce the target of opportunity for RFID/MEMS. However, even 25% reductions in key benefit elements produced only an 11% reduction in ROI, and a 21% reduction in NPV. Hence, estimates of return are sensitive to mis-estimates of cost reduction, but even a 25% mis-estimate still yields an NPV over one billion dollars, and a ROI over 100%.

Limitations

This research was funded by in part by stakeholders with a vested interest in the success of the ATOS program. In part, that compensation paid for a software tool we developed to allow the ATOS program office to independently conduct the sort of risk and sensitivity analysis reported here. The funding also supported some of the analysis to develop the results we report here. While our sponsor sought an objective, unbiased analysis, the potential for unintended bias in sponsored research is well understood and remains a limitation of this work.

We did not attempt to directly model the application development costs required to exploit the RFID/MEMS data. We dealt with this omission in part by modeling variance in expected cost reductions, but a limitation of this research is that these costs may be greater than anticipated, and hence reduce the reported returns.

Status quo inventory costs are held constant in the risk and sensitivity analysis. As there are other initiatives being implemented to reduce these costs, or to avoid future cost growth, this is not a conservative approach. Lacking details about other efforts underway, excluding status quo inventory costs from the risk analysis seems reasonable, given the scope of our analysis. However, it remains a limitation of this analysis that we

do not address the risk of continued investment in other inventory projects that might reduce the cost reduction and cost avoidance opportunities in the status quo.

Conclusions and Summary

We have developed a multiple attribute utility structure for the implementation of a major RFID/MEMS application, in which safety, manpower issues, and readiness (related to what is called safety capacity in the commercial sector) are all seen as important non-cost benefits. Our limited analysis of this utility structure shows that cost reduction may not capture all, or even most of the utility to be derived from such technology. We also saw resistance to change in our limited sample, potentially representing an implementation barrier. However, our cost analysis showed that this RFID/MEMS application should produce substantial cost savings, and our sensitivity analysis suggested that these savings were robust against moderate mis-estimates from our subject matter experts. These savings may justify the investment without weighing qualitative factors. When the cost savings are not as clear and robust as they are in this case, it remains important with RFID, as with other operations technologies, to be able to systematically weigh such non-cost benefits, and implementation obstacles.

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